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TOWARD A NONPARAMETRIC COVARIANCE ANALYSIS OF A WEATHER MODIFIC--ETC(U)
AUG 77 R J SERFLING N00014-76-C-0394

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10 by R. J. Serfling

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Department of Statistics
The Florida State University
Tallahassee, Florida 32306

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ABSTRACT

TOWARD A NONPARAMETRIC COVARIANCE ANALYSIS OF A WEATHER MODIFICATION EXPERIMENT

A further analysis of the 1967-74 Santa Barbara weather modification experiment data is in progress in the Department of Statistics, Florida State University. The present report provides a nonparametric covariance analysis, of limited scope, of the Phase I experimental data. The findings tend to confirm, *qualitatively*, the North American Weather Consultants conclusions of a demonstrable seeding effect under selected conditions of cloud instability and cloud temperature. Quantitively, however, the present findings are more restrained. The analysis tends to suggest the need for improved experimental designs.

1. Introduction. A series of weather modification experiments was conducted from 1967-74 by North American Weather Consultants (NAWC) under the sponsorship of the Naval Weapons Center, China Lake, California. The experiments were carried out at Santa Barbara, California, with the objective of evaluating the effectiveness of cloud seeding and seeding methods in West Coast cyclonic winter and spring storms. During Phase I, covering the 1967-68 through the 1970-71 seasons, the primary seeding mode was ground based. During Phase II, covering the 1971-72 through the 1973-74 seasons, the seeding mode was aerial. An overview of the experiments and NAWC's data analysis is provided in the final report [3].

In [3] the data was organized and analyzed on a *station-by-station* basis. There were two networks of raingage stations, those in the "target" area and those in the "control" area. During Phase I, the experimental units consisted of 107 "seedable" convection bands, each of which passed through both the control and target areas. By a random process, 56 experimental units were selected for actual seeding. For each raingage station, the raingage precipitation measurements for the 56 seeded bands were averaged and likewise the average for the 51 nonseeded bands was formed, and the ratio of these two averages was taken as a basic quantitative variable measuring seeding effect. The effect of seeding was then assessed by comparing the ratios for target network stations with those for the control area. Table 1 gives the distribution of stations by magnitude of ratio (seeded band average/nonseeded band average), for control and target areas.

Table 1. Number of Stations, by Magnitude of Precipitation Ratio, by Control and Target Areas.

Magnitude of Ratio	Number of Stations: Control Area	Number of Stations: Target Area
Under 1.000	6	1
1.000-1.195	20	6
1.200-1.395	10	20
1.400-1.595	3	22
Over 1.600	0	12
Total	39	61

Source: Derived from [3], Appendix II. (Also produced in [4], page 10)

The target area ratios appear to be stochastically larger than the control area ratios, indicating that seeding tends to yield an increase in precipitation. However, it is difficult to test the statistical significance of such a result, due to the stochastic dependence among the ratios (the ratios, being based on averages taken over the same experimental units, would be highly correlated for stations in close proximity). Moreover, the control area ratios exceed the value 1 with peculiarly high frequency, thus making it difficult to interpret the meaning of a high value for such a precipitation ratio. Nor does this approach lead to a *quantitative* determination of the seeding effect, in the sense of a measure of the actual increase in precipitation produced over the target area as a whole. Because of issues such as these, it appears reasonable to explore other approaches toward analysis of the data, before concluding that "beyond any reasonable doubt the seeding was successful in increasing rainfall in a prespecified area" [1].

A further analysis of the Santa Barbara data, for Phase I, has been launched in the Department of Statistics, Florida State University, under the

direction of Ralph A. Bradley. The data is being organized and analyzed by *individual bands* (experimental units). As an initial step, a summarization of the precipitation data by response surface methods has been carried out and reported by Bradley, Srivastava and Lanzdorf [4]. For each experimental unit, separately over the control and target areas, response surfaces are fitted to the raingage measurements. These surfaces provide a framework for development of a variety of analyses.

The present paper augments [4]. The data is again organized by individual bands, but instead of a response surface approach the quantity of rainfall over a network of stations is represented by the simple average of raingage measurements. (It is felt, on the basis of some casual theoretical reflections, that these traditionally used measures are highly correlated with volumes obtained by integrating under surfaces.) Further, the experimental units are *grouped not only* by "seeded" or "nonseeded," but also by covariates corresponding to (1) the stability of the convection band, (2) the 500 mb temperature of the convection band. This provides a framework for a nonparametric covariance analysis of the data. Section 2 presents the relevant tabulations and computations; Section 3 presents conclusions, findings and recommendations.

2. <u>Tabulations and computations</u>. Table 2 provides a classification of the 107 Phase I experimental units by "seeded" or "nonseeded," by air mass stability, and by 500 mb cloud temperature. Following [1], the air mass stability categories are taken to be

UH: Unstable, High Convective Instability Base (CIB)

UL: Unstable, Low CIB

S: Stable,

and the 500 mb temperature categories are taken to be

Cold: -22.5°C. or below

Medium: Above -22.5°C., below -17.5°C.

Warm: -17.5°C. or above.

Refer to [1] for discussion of the meteorological significance of these categories.

Table 2. Number of Experimental Units, by Seeded or Nonseeded, by Stability Category and by Temperature Category.

Stability Category	Temperature Category							
	Cold		Medium		Warm		Total	
	S	NS	S	NS	S	NS	S	NS
UH	1	5	7	6	3	1	11	12
UL	16	12	14	11	10	11	40	34
S	0	0	5	1	0	4	5	5
Total	17	17	26	18	13	16	56	51

Note the imbalances within

a) the UH row

b) the S row

c) the Medium column

d) the Warm column.

These cause a confounding of certain comparisons between seeding and nonseeding, for example the comparison of S versus NS for the UH category. It is thus

desirable to analyze the data separately *within* the cells of Table 2. Corresponding to a labelling of the cells according to the pattern

1	2	3
4	5	6
7	8	9

Tables A1-A9 (A7 omitted) provide for each cell the average precipitation for control stations, the average precipitation for target stations, and the ratio of target average to control average, by bands classified seeded or nonseeded. (These tables are derived from the sources [1] and [2].)

Table A1. For Phase I Bands in "UH" Stability Category and "Cold" Temperature Category: Average Precipitation for Control Stations, Average Precipitation for Target Stations, and Ratio of Target Average to Control Average, by Bands Classified Seeded or Nonseeded.

Nonseeded Bands				Seeded Bands			
Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X	Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X
68-69,#31	.183	.228	1.25	68-69,#34	.737	1.266	1.72
#33	.115	.106	.92				
#41	.522	.410	.79				
70-71,#12	.267	.267	1.00				
#13	.043	.108	2.51				

Table A2. For Phase I Bands in "UH" Stability Category and "Medium" Temperature Category: Average Precipitation for Control Stations, Average Precipitation for Target Stations, and Ratio of Target Average to Control Average, by Bands Classified Seeded or Nonseeded.

Nonseeded Bands				Seeded Bands			
Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X	Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X
68-69,#4	.156	.072	.46	68-69,#6	.163	.158	.97
#9	.093	.048	.52	#8	.232	.246	1.06
#25	.025	.062	2.48	#24	.043	.197	4.32
#37	.567	.867	1.53	#26	.140	.177	1.26
#39	.147	.114	.78	#28	.170	.087	.51
69-70,#3	.052	.070	1.35	#30	.270	.357	1.32
				69-70,#8	.318	.172	.54

Table A3. For Phase I Bands In "UH" Stability Category and "Warm" Temperature Category: Average Precipitation for Control Stations, Average Precipitation for Target Stations, and Ratio of Target Average to Control Average, by Bands Classified Seeded or Nonseeded.

Nonseeded Bands				Seeded Bands			
Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X	Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X
68-69,#12	.247	.326	1.34	68-69,#5	.080	.036	.45
				#11	.090	.113	1.26
				#36	.217	.204	.94

Table A4. For Phase I Bands in "UL" Stability Category and "Cold" Temperature Category: Average Precipitation for Control Stations, Average Precipitation for Target Stations, and Ratio of Target Average to Control Average, by Bands Classified Seeded or Nonseeded.

Nonseeded Bands				Seeded Bands			
Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X	Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X
67-68,#1	.177	.091	.51	67-68,#4	.078	.049	.63
#2	.207	.203	.98	#7	.097	.080	.82
#3	.083	.168	2.02	#16	.150	.128	.85
#22	.105	.068	.65	#19	.543	.698	1.28
68-69,#32	.400	.554	1.38	#20	.027	.060	2.22
69-70,#14	.237	.593	2.50	#21	.087	.086	.99
#17	.300	.221	.74	69-70,#18	.100	.199	1.99
#20	.120	.123	1.02	#19	.162	.091	.56
70-71,#8	.240	.252	1.05	#21	.093	.242	2.60
#14	.720	.850	1.18	#22	.813	1.016	1.25
#17	.078	.056	.72	70-71,#9	.052	.047	.90
#19	.023	.085	3.69	#10	.073	.155	2.12
				#11	.267	.478	1.79
				#15	.085	.115	1.35
				#16	.178	.074	.42
				#18	.158	.210	1.33

Table A5. For Phase I Bands in "UL" Stability Category and "Medium" Temperature Category: Average Precipitation for Control Stations, Average Precipitation for Target Stations, and Ratio of Target Average to Control Average, by Bands Classified Seeded or Nonseeded.

Nonseeded Bands				Seeded Bands			
Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X	Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X
67-68,#6	.092	.081	.88	67-68,#5	.122	.146	1.20
#9	.020	.009	.45	#8	.010	.004	.40
#18	.257	.131	.51	#15	.163	.273	1.67
68-69,#14	.125	.060	.48	68-69,#23	.132	.383	2.90
#19	.085	.272	3.28	69-70,#2	.363	.345	.95
#20	.312	.670	2.15	#5	.257	.356	1.39
#35	.432	.360	.83	#12	.023	.433	18.83
69-70,#1	.628	.433	.69	#13	.053	.065	1.23
#6	.213	.237	1.11	#15	.513	.444	.87
#7	.048	.027	.56	#16	.405	.528	1.30
70-71,#22	.358	.295	.82	70-71,#4	.050	.081	1.62
				#6	.182	.991	5.45
				#7	.114	.334	2.93
				#21	.340	.283	.83

Table A6. For Phase I Bands in "UL" Stability Category and "Warm" Temperature Category: Average Precipitation for Control Stations, Average Precipitation for Target Stations, and Ratio of Target Average to Control Average, by Bands Classified Seeded or Nonseeded.

Nonseeded Bands				Seeded Bands			
Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X	Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X
67-68,#10	.027	.029	1.07	67-68,#14	.118	.087	.69
#11	.165	.210	1.27	68-69,#13	.165	.184	1.12
#12	.255	.275	1.08	#16	.162	.348	2.15
#13	.063	.067	1.06	#17	.310	.469	1.51
68-69,#10	.023	.035	1.52	#18	.227	.599	2.64
#15	.297	.268	.90	#22	.417	.898	2.15
#21	.535	.670	1.25	69-70,#11	.148	.126	.85
#27	.200	.181	.90	70-71,#1	.358	.135	.38
69-70,#10	.122	.120	.98	#3	.168	.136	.81
70-71,#2	.152	.104	.68	#20	.475	.525	1.10
#5	.018	.085	4.72				

Table A8. For Phase I Bands in "S" Stability Category and "Medium" Temperature Category: Average Precipitation for Control Stations, Average Precipitation for Target Stations, and Ratio of Target Average to Control Average, by Bands Classified Seeded or Nonseeded.

Nonseeded Bands				Seeded Bands			
Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X	Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X
68-69,#29	.062	.076	1.22	67-68,#17	.870	.633	.73
				68-69,#3	.068	.084	1.24
				#38	.075	.085	1.13
				#40	.391	.688	1.76
				69-70,#4	.025	.034	1.36

Table A9. For Phase I Bands in "S" Stability Category and "Warm" Temperature Category: Average Precipitation for Control Stations, Average Precipitation for Target Stations, and Ratio of Target Average to Control Average, by Bands Classified Seeded or Nonseeded.

Nonseeded Bands				Seeded Bands			
Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X	Season and Band No.	Avg. Precip., Control Stat. X	Avg. Precip., Target Stat. Y	Precip. Ratio R = Y/X
68-69,#1	.282	.177	.63				
#2	.202	.171	.85				
#7	.097	.067	.69				
69-70,#9	.177	.122	.69				

A natural approach is to analyze the ratios R provided in Tables A1-A9. However, a mere glance at Tables A1, A3, A8 and A9 reveals in each case an insufficient amount of data to yield any statistically significant findings. The situation is only slightly better in the case of Table A2, but upon close analysis it is found that the null hypothesis of "no seeding effect" cannot be rejected by any reasonable statistical test. This is a consequence of the high variability, within seeded and nonseeded groups, of the ratios R. The preponderance of the data falls in cells 4, 5 and 6, and so it might be hoped that definitive conclusions may be reached via Tables A4, A5, and A6. However, the difficulty with Table A2 persists: the variability of the R-ratios overwhelms the possibility of testing for significant difference between the seeded and nonseeded cases. Table 3 provides for each of cells A4, A5, and A6 the average $\overline{R}_S$ of R-values for seeded bands, the average $\overline{R}_{NS}$ of R-values for nonseeded bands, and the estimated standard deviation of the difference $D = \overline{R}_S - \overline{R}_{NS}$.

Table 3.

Cell	$\overline{R}_S$	$\overline{R}_{NS}$	D	σ_D
A4	1.32	1.37	- .05	.30
A5	2.97	1.07	1.90	1.25
A6	1.34	1.40	- .06	.39

Therefore, the R-ratios in Tables A1-A9 may be abandoned. (The value D = 1.90 for Table A5 appears to provide strong evidence in support of a seeding effect, until it is noted that one of the contributors to $\overline{R}_S$ is the R-value 18.83 for $R = Y/X$ with a denominator X close to 0.) The approach of looking at these R-values would become feasible only if a considerably larger number of experimental units were available.

In lieu of R-ratios, $R_i = Y_i/X_i$, an alternative ratio-type approach is based on the ratios

(1) $$R = (\Sigma Y_i)/(\Sigma X_i),$$

taken separately over the seeded and nonseeded units. This reduces the excessive influence of small X_i-values, but it measures a less interesting parameter. Table 4 provides for each of the cells A4, A5 and A6 the ratio R_S of form (1) for seeded bands, the ratio R_{NS} of form (1) for nonseeded bands, and the estimated standard deviations of R_S and R_{NS}.

Table 4.

Cell	R_S	σ	R_{NS}	σ
A4	1.22	.02	1.21	.03
A5	1.71	.08	1.00	.05
A6	1.38	.06	1.10	.01

It is evident that, as measured by $R_s - R_{NS}$, for cells A5 and A6 there is a clear-cut statistically significant seeding effect. It is especially pronounced for A5.

REMARKS. (*i*) The control stations numbered 6, the target stations 54, in the experiment as described in [1]. Subsequently, data was provided for additional control stations and additional target stations. However, a parallel development of Tables A1-A9 and Tables 3 and 4 yields essentially similar results. Herein we have presented the version suitable for direct comparison with [1].

(*ii*) An analysis of the R-ratios with respect to medians instead of means, $\bar{R}_S$ and $\bar{R}_{NS}$, leads to essentially similar results.

(*iii*) A number of plots associated with Tables A1-A9 were constructed and examined. These provided little additional insight of definitive nature.

3. <u>Comments</u>. The analysis of Section 2 yields the following general conclusions:

(*i*) The data is insufficient to yield positive affirmation or rejection of the "null" hypothesis, except in certain cases. These cases correspond to the "UL" stability category, especially the "Medium" and "Warm" temperature range.

(*ii*) In the "UL" - "Cold" case, the null hypothesis appears well substantiated.

(*iii*) In the "UL" - "Medium" case, the null hypothesis appears very strongly rejected.

(*iv*) In the "UL" - "Warm" case, the null hypothesis appears strongly rejected.

While not in severe contradiction to the findings in [1], [2], [3], the above conclusions are considerably more restrained. They are solely qualitative, not quantitative.

With greater investment of time and sophistication, a more informative version of the nonparametric covariance analysis presented here might be carried out. However, the gain would be slight compared to the reward which might accrue from an experimental design of greater sophistication and with a greater number of experimental units. For example, one might achieve greater within-cells balance between seeding and nonseeding.

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20. ABSTRACT

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